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Modeling of Echoes From Extended Targets in Shallow Water

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PREFACE

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13. ABSTRACT (Maximum 200 words)

This document describes an effort to integrate existing target and environmental models to allow the prediction of echoes from targets in a shallow water environment using realistic transmitted waveforms. A primary objective was the development of a numerical tool that could examine the effect of a medium on target echo characteristics. Echoes were generated and comparisons made in a shallow water environment by using a linear frequency modulated signal, the generic sonar model, and the frequency response functions of a rigid sphere and an array of five spheres.

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MODELING OF ECHOES FROM EXTENDED TARGETS IN SHALLOW WATER

The objective of this work was to integrate existing target and environmental models to allow the prediction of echoes from targets in a shallow water environment using realistic transmitted waveforms. A primary goal was the development of a numerical tool that could examine the effect of the medium on target echo characteristics.

SLIDE 1

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OBJECTIVES

- **INTEGRATE TARGET AND ENVIRONMENTAL MODELS TO PRODUCE CAPABILITY OF PREDICTING ECHOES FROM TARGETS IN A SHALLOW WATER ENVIRONMENT USING REALISTIC TRANSMITTED WAVEFORMS.**
- **UTILIZE NUMERICAL TOOL TO EXAMINE THE EFFECT MEDIUM HAS ON TARGET ECHO CHARACTERISTICS.**

SLIDE 2

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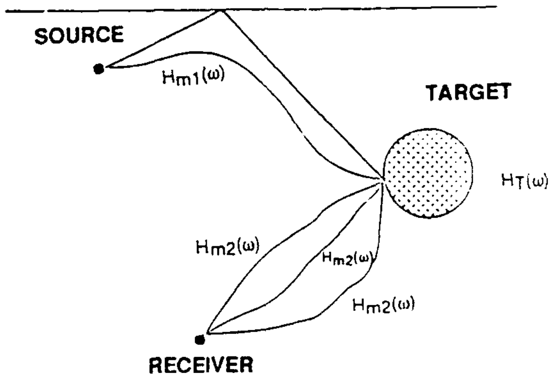
REPRESENTATION OF GENERATED ECHO IN FREQUENCY DOMAIN

ECHO $R(\omega) = H_{TOT}(\omega)S(\omega)$

SIGNAL $S(\omega) = \int x(t)e^{-i\omega t}dt$

TOTAL TRANSFER FUNCTION $H_{TOT}(\omega) = H_{m1}(\omega)H_T(\omega)H_{m2}(\omega)$



$H_{mi}(\omega)$ FROM GENERIC SONAR MODEL (GSM)

$H_T(\omega)$ TARGET RESPONSE

Slide 2 illustrates a source target and receiver arrangement. Knowing the transmitted signal x(t) allows prediction of the received signal. The echo in the frequency domain is generated by assuming the frequency representation of the echo to be the product of the frequency response of the transmitted signal S(ω) and the frequency response of the total target-medium system. The frequency response of the transmitted signal is, of course, just the transform of x(t). The transfer function of the total target-medium system is the product of the transfer function of the medium for the path from the source to the target, the frequency response of the target, and the frequency response of the medium from the target to the receiver. The transfer function of the medium is generated using the generic sonar model (GSM). The GSM produces eigenray files from which the amplitudes and phases of the eigenrays from the source to the target are obtained. The GSM also provides the angles at which the eigenrays leave the source and arrive at the target. Conversely, the GSM gives the angles at which the eigenrays leave the target and arrive at the receiver. These angles are important because the target response depends on the angles of incoming and outgoing rays. The target transfer function is given by the frequency response of either a rigid sphere or an array of five spheres in the Rayleigh region.

Although this slide depicts a bistatic arrangement, the results discussed here will be for the monostatic case where the source and receiver are collocated.

SLIDE 3

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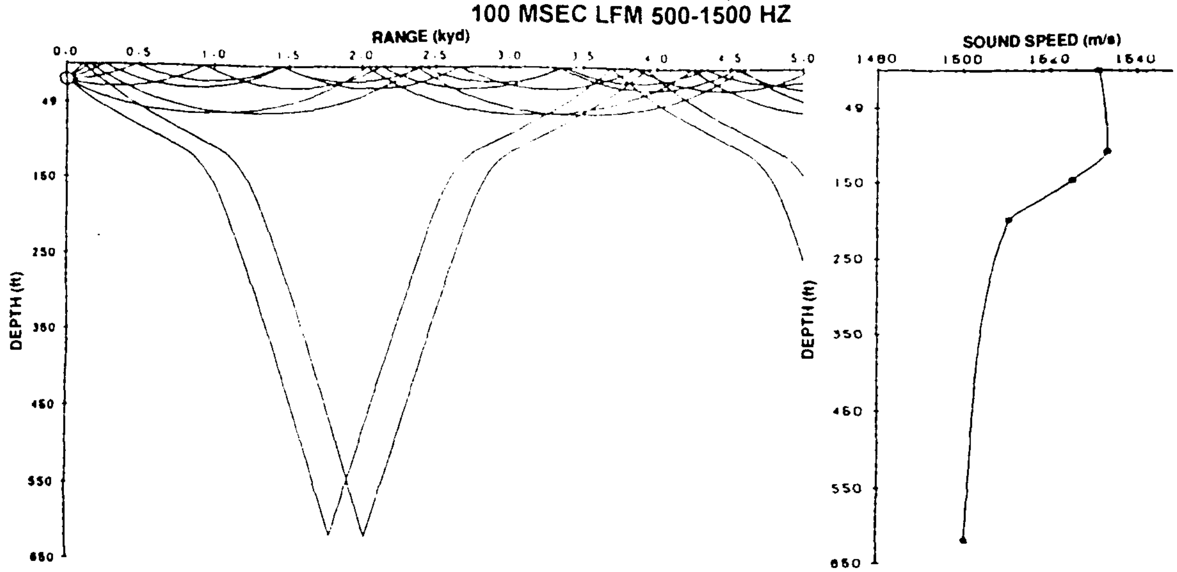
GSM GENERATED RAYTRACE AND SOUND VELOCITY PROFILE
OF SHALLOW WATER ENVIRONMENT

SOURCE DEPTH =20 FT TARGET RANGE =3.8 KYD
TARGET DEPTHS =20FT, 200 FT
100 MSEC LFM 500-1500 HZ



Slide 3 illustrates a sound velocity profile and the GSM-generated raytrace. The shallow water environment depicted here has a depth of 620 feet. The source is located at a depth of 20 feet, and the range from the source to the target is 3.8 kyd. Two target depths at this range will be discussed: one at 20 feet and the other at 200 feet. A surface duct exists down to 50 feet. One target depth is in the surface duct and one is below it.

The 100-msec linear frequency modulated (LFM) signal is transmitted within a frequency band of 500 to 1500 Hz.

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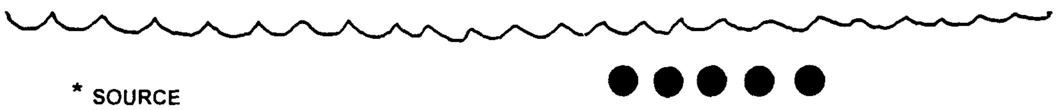
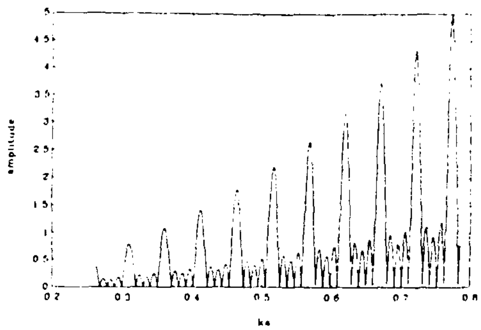
ARRAY OF SCATTERERS



TRANSFER FUNCTION OF ARRAY



FIVE SPHERICAL SCATTERERS
RADIUS =.125m
SPACING =25 FT (7.62m)
TOTAL LENGTH =100 FT

As stated earlier, the targets in the following examples were either an array of spheres (shown here) or a rigid sphere. As can be seen from slide 4, the array has five equal scatterers separated by 25 feet, resulting in a total target length of 100 feet. The transfer (form) function, or frequency response, for this array is shown at the lower left of the slide. A grating pattern is observed due to the even spacing of the scatterers. The form function shown is calculated for a 180-degree backscatter for incidence along the line of the array as it is configured here.

SLIDE 5

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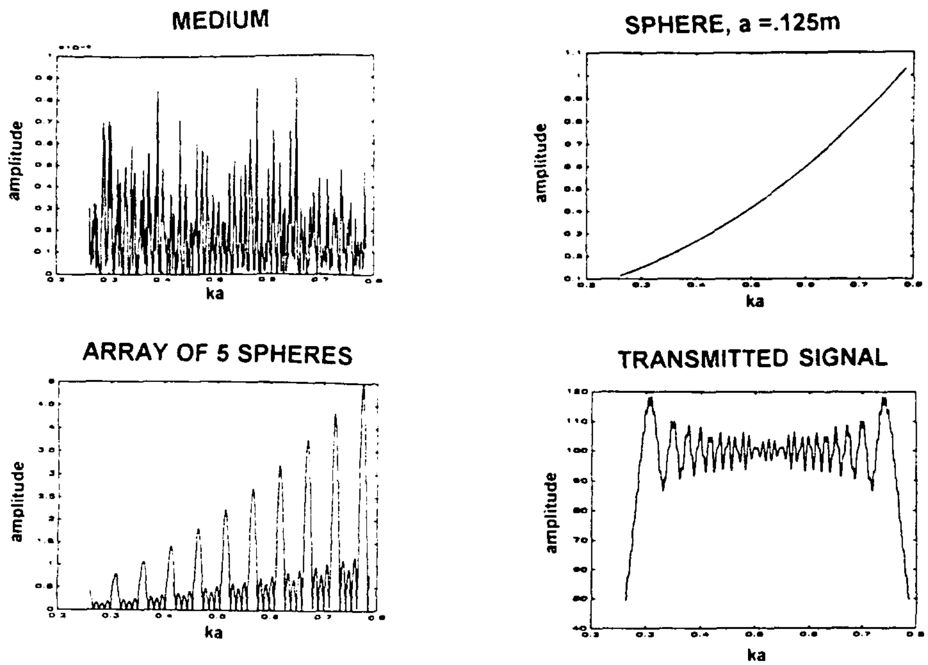
FREQUENCY RESPONSES OF MEDIUM AND TARGETS
(TARGET DEPTH =200 FT)



For a point target at a range of 3.8 kyd and a depth of 200 feet, the GSM produces the frequency response of the medium as shown in the upper left plot. This occurs as the result of calculating the medium response out to the target position and then back to the receiver. The ka values range from about 0.3 to about 0.8.

The upper right plot of the slide shows the frequency response of a rigid sphere in the Rayleigh region. The form function increases with ka because of a direct k-squared dependence. Also shown is the frequency response of the array of five spheres (lower left) as well as the frequency response of the transmitted LFM signal (lower right).

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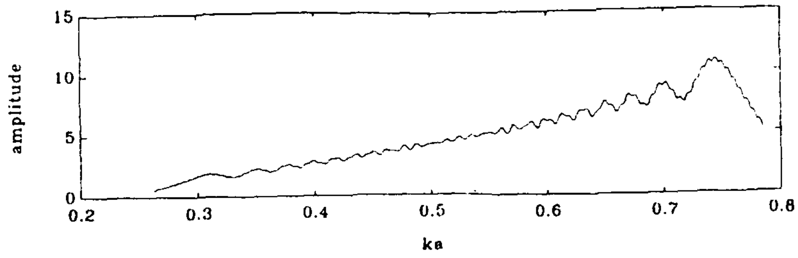
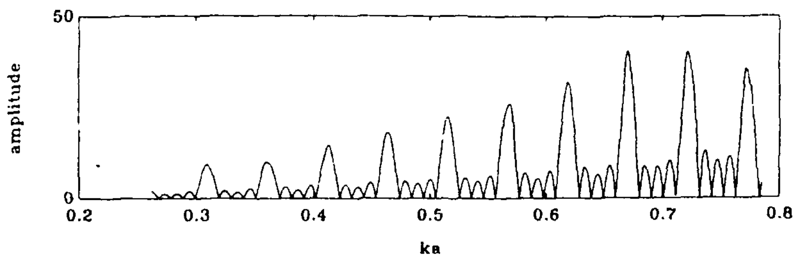
ECHO FREQUENCY REPRESENTATIONS

SPHERE, a =.125m



ARRAY OF 5 SPHERES



The frequency responses of the echoes due to the incident LFM signal for the rigid sphere and array of five spheres are generated in free space, without a medium, using the frequency responses of the two targets. As can be seen in the upper plot of this slide, the frequency response of the rigid-sphere echo shows a rise in amplitude as the frequency is increased. The turn near ka = 0.8 is due to the signal. For the echo from the array of five spheres, as shown in the bottom plot, the frequency response has a series of peaks similar to the array without the signal (bottom left plot of slide 5), although their relative amplitudes have changed.

SLIDE 7

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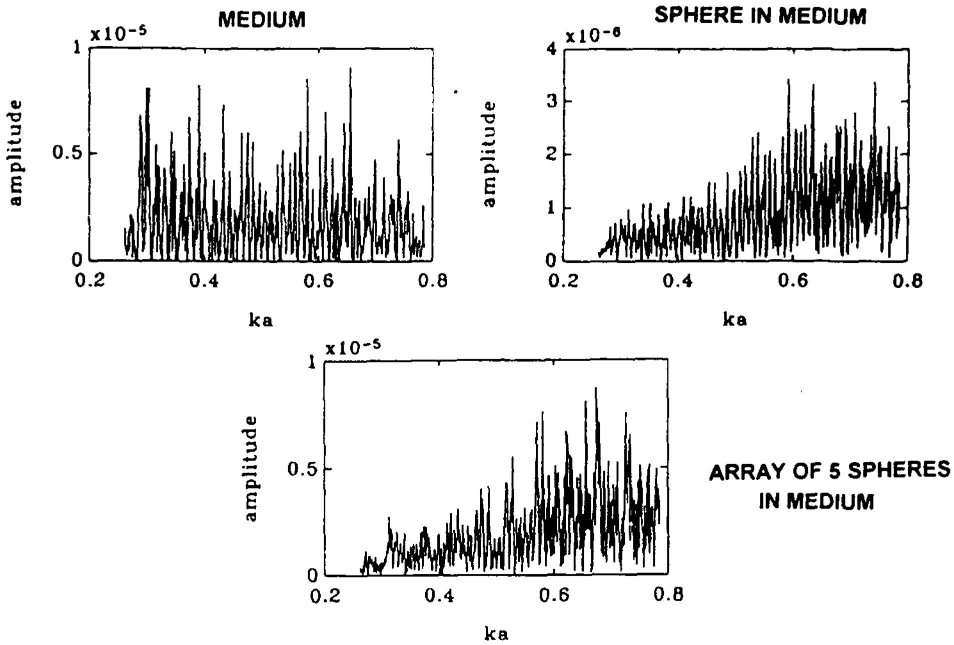
ECHO FREQUENCY REPRESENTATIONS

(TARGET DEPTH =200 FT)



Placing the sphere and the array of spheres into the medium at a depth of 200 feet produces the results seen in slide 7. Here, the echo in frequency space for the medium alone is shown in the upper left plot. The sphere in the medium exhibits a similar response in that many peaks are observed. However, due to the frequency response of the sphere without the signal, the overall shape of the echo is different from that of the medium alone. The lower frequencies have a relatively lower amplitude (compared with the higher frequencies) than they do for the echo from the medium alone. The maximum amplitude for the echo from the sphere in the medium is about an order of magnitude below the maximum amplitude of the medium alone. This is, of course, due to the behavior of the sphere form function, which is a monotonically increasing function of frequency over the 500- to 1500-Hz frequency band, ranging from about 0.1 to 1.0 (as seen in the upper right plot of slide 5).

Examining the echo from the array in the medium shows a different characteristic in the frequency response. The amplitudes at the lower frequencies are lower than for the echo from the medium alone. The peaks in the echo from the array have broader bases, and a higher Q, than do the peaks in the echo from the medium. The broadening of the peaks gives an indication of the presence of the target at this depth.

SLIDE 8

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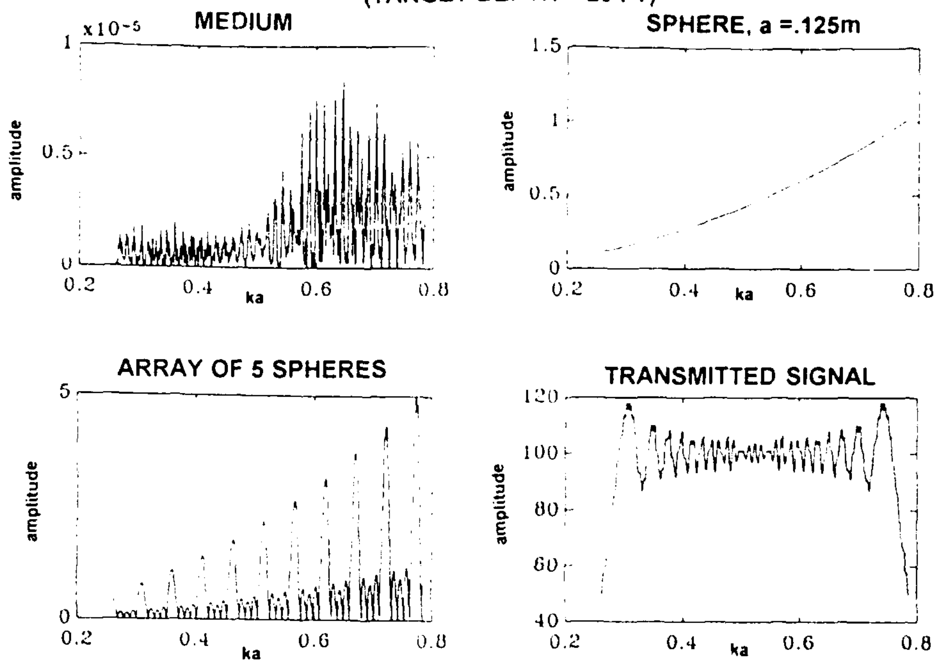
FREQUENCY RESPONSES OF MEDIUM AND TARGETS
(TARGET DEPTH = 20 FT)



In slide 8, the target is now located at a depth of 20 feet within the surface duct. The frequency response for the medium alone is shown in the upper left plot. As can be seen, the lower frequencies have a lower amplitude response. There is almost a step function observed as we move from the lower to the higher ka values.

The slide also illustrates the rigid sphere response, the array response, and the frequency response of the LFM transmitted signal.

The plots shown for the medium and the targets do not incorporate any signal.

SLIDE 9

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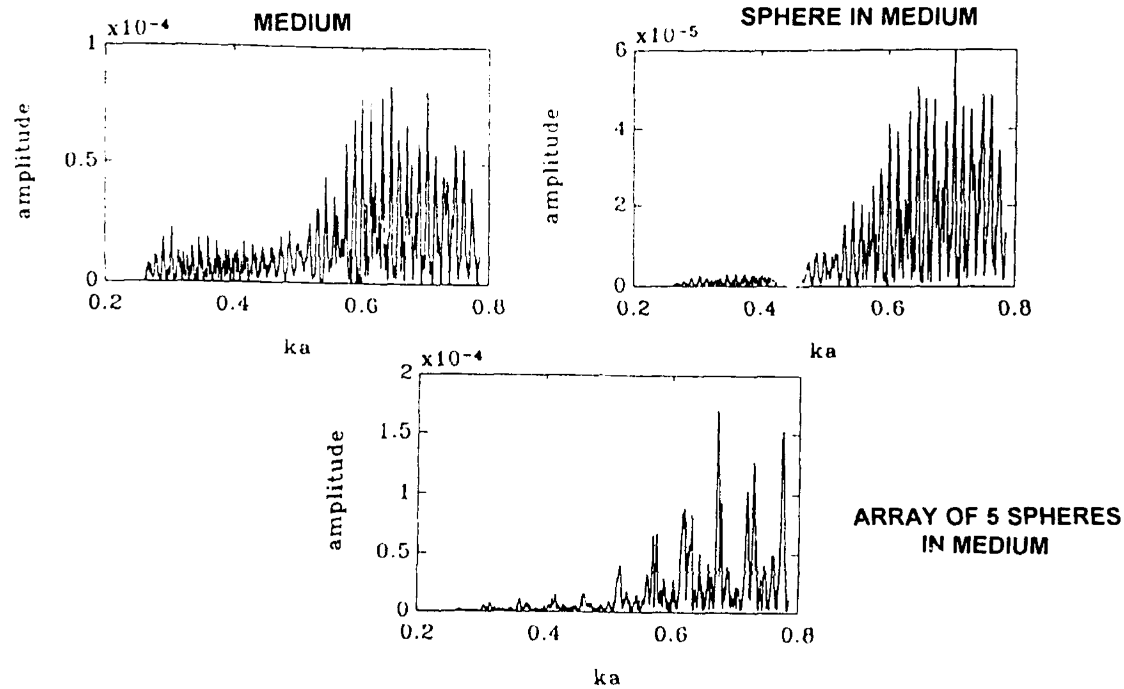
ECHO FREQUENCY REPRESENTATIONS

(TARGET DEPTH = 20 FT)



The frequency responses of the echoes from the medium, the sphere in the medium, and the array in the medium are plotted in slide 9 for a target depth of 20 feet. The echo from the medium is shown at the upper left. A pattern similar to the medium frequency response is seen. The lower frequencies (ka less than 0.6) have a lower amplitude than the higher frequencies (ka greater than 0.6).

The sphere in the medium produces an echo with a shape similar to the echo from the medium alone, but with about an order of magnitude difference in amplitude, due to the response of the sphere in the 500- to 1500-Hz frequency region.

The echo from the array in the medium shows a different pattern than the echo from the medium alone. The presence of the target is very evident in the sets of wide peaks, which were also observed in the array response. The peaks in the frequency response of the array in the medium have much broader bases (a higher Q) than the peaks in the medium-alone echo.

SLIDE 10

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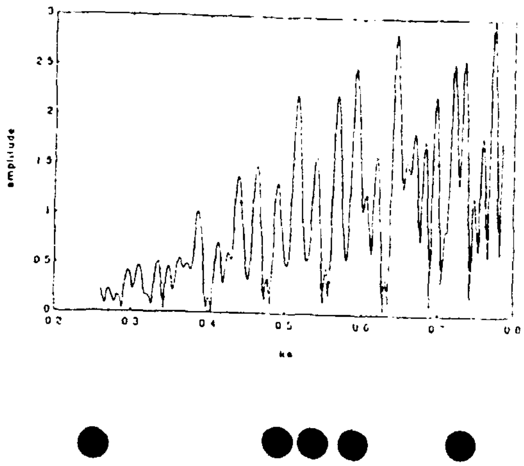
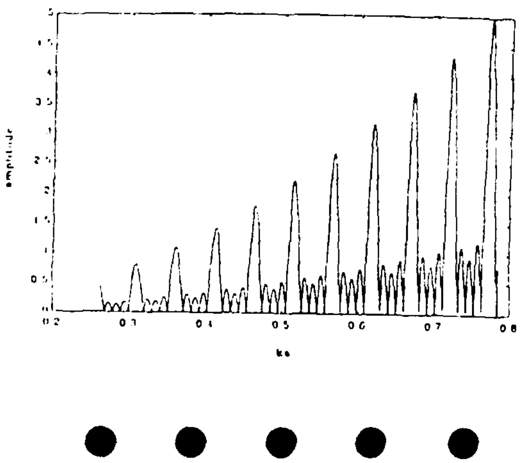
TRANSFER FUNCTIONS OF ARRAYS

UNEVENLY SPACED ARRAY



EVENLY SPACED ARRAY



Misaligning two scatterers in the array produces the frequency response shown on the left-hand side of slide 10. The even pattern of peaks shown in the equally spaced array at the right has been destroyed, producing an oscillatory pattern with few zeroes.

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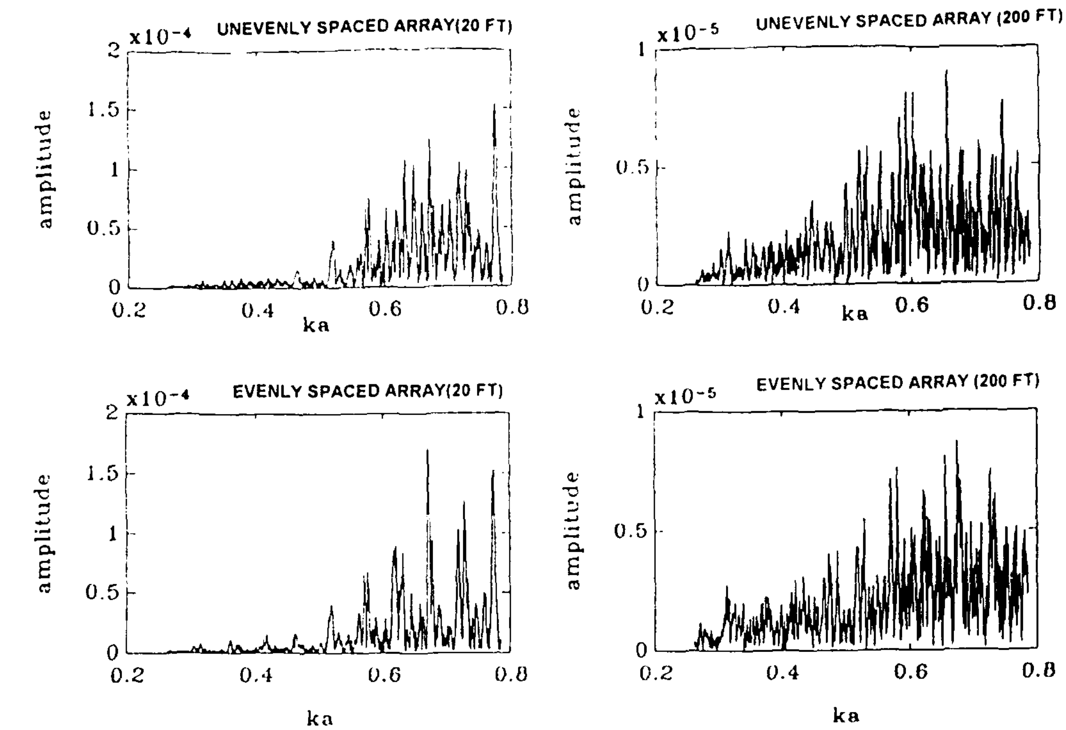
FREQUENCY REPRESENTATIONS OF ECHOES FROM ARRAYS IN MEDIUM AT DEPTHS OF 20 FT AND 200 FT



In the top portion of slide 11, the unevenly spaced array is placed in the medium at depths of 20 and 200 feet, and the resulting echoes are compared to echoes from the evenly spaced array shown previously in slides 5 and 9 (reproduced at the bottom of this slide). The echo from the unevenly spaced array shows the same broadening of the peaks when compared with the medium-alone echo as does the echo from the evenly spaced array. The echoes from the two types of array appear similar at the 200-foot depth.

At the 20-foot depth, shown on the left of the slide, the frequency responses differ. The peaks in the evenly spaced array are grouped more distinctly and are broader than the peaks in the unevenly spaced array, although some peaks exist in both sets of echoes in the medium. This is due, in part, to each array having the same overall length as well as the same position for three of the five scatterers.

SLIDE 12

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CONCLUSIONS

- ECHOES WERE GENERATED USING AN LFM SIGNAL, GSM, AND FREQUENCY RESPONSE FUNCTIONS OF A SPHERE AND AN ARRAY OF SPHERES AT TWO DEPTHS IN A SHALLOW WATER ENVIRONMENT.
- TRANSFER FUNCTION OF EXTENDED TARGET DISPLAYED REPETITIVE PATTERN.
- OSCILLATIONS IN TRANSFER FUNCTION OF EXTENDED TARGET WAS EVIDENT IN THE FREQUENCY REPRESENTATION OF THE ECHOES OF THE EXTENDED TARGET IN THE MEDIUM AT BOTH DEPTHS.
- THE PRESENCE OF TARGETS WITH RAPIDLY VARYING TRANSFER FUNCTIONS WAS MORE PRONOUNCED IN THE ECHO FREQUENCY REPRESENTATIONS OF THE TARGET IN THE MEDIUM THAN FOR A TARGET WITH A MONOTONIC RESPONSE.

In conclusion, we have shown the capability for generating echoes with an LFM signal, the GSM, and the frequency response functions of a rigid sphere and an array of spheres in a shallow water environment.

The extended targets (the evenly and unevenly spaced arrays) exhibited an oscillatory pattern that was evident from their echoes in the medium at both depths examined. The evenly spaced array displayed a repetitive pattern that was discernible in the echo from the array in the medium at 20 feet. The presence of targets with rapidly varying frequency responses (i.e., the extended arrays) was more pronounced in the echo frequency representations of the targets in the medium than in the echoes from a target with a smooth, monotonic response, such as the rigid sphere used in this study.

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